Dave 9/4/02
Ver 17 ch 5&6
comments

5. FINDINGS

5.1. GENERAL

As with any model, the potential for misuse of the results is possible. Prior use of the large-scale physical models (WES or University) restricted who could conduct model studies because of space, costs, and operational requirements. As a result, model results were produced, processed and analyzed under the direction of persons trained and experienced in physical loose-bed modeling. The advent of micromodels as a viable engineering tool removes much of the restriction to a relatively few individuals/entities because micromodels are relatively small and affordable. Thus, widespread use of these models by inexperienced modelers is a concern. This concern also exists for numerical models. Today's availability of inexpensive computers and modeling software provides a means for almost anyone to open shop as an "expert" hydraulic/sedimentation modeler. Simply having a computer and modeling software does not warrant many claims of modeling competence in government, university and private sector arenas. Likewise, having micromodel equipment does not guarantee that model results are interpreted appropriately. (This statement serves no purpose…having the use of any model, whether it be Hec-2…a large fixed bed model, a navigation towboat model, etc..always faces the possibility of someone becoming an "expert".

While the concern about inappropriate model use is not restricted to micromodels, the avenue for model misapplication by individuals having insufficient training in river hydraulics, sedimentation, becomes a distinct likelihood. This is particularly true given the meager cost of setting up a micromodel lab (Don't agree with this…setting up a micro model is not a meager cost..and..we will not allow other Corps Districts to just "set-one-up".(the 3-D laser scanner, the most expensive component of present micromodel equipment, is considered optional).

cost is relatively meager ~$25,000-30,000

can't see how MVS can restrict other Corps Dist & the public

Future use of micromodels requires a set of safeguards to ensure that only experienced river and hydraulic engineers (emphasis on both aspects) conduct micromodel studies and interpret micromodel results. (Already established and in place…if someone wants to set a facility up, they must let us train them and oversee their modeling)

Won't go into legalities, but what we have now is not sufficient

5.2. POINTS TO CONSIDER

The evaluation of any topic raises the specter of criticism. The perceived criticism can be taken as an affront to the method, technique, or capability of a particular approach. There may also be a personal connotation on the part of the one who performed the work.

Evaluation of a technology must include an assessment of previous works. Because the very nature of a qualitative model or approach indicates a lack of perfect agreement with the real world, the review often identifies some deficit or deviation between the model result and the observed prototype behavior. Such is the case for both large- and small-scale loose-bed models. Neither of these model approaches has claimed to exactly reproduce prototype conditions. As such, a review of previous large- and small-scale models reveals differences between model results and the prototype -- a fact completely expected.

In this context, defining capabilities and limitations for such models must consider the fact that the models (and modelers) were constrained from the onset. Of those model studies included herein, calibration or verification of the model bathymetry served as the sole assessment factor when determining its suitability for alternative testing. The modeler's judgement regarding whether the model was calibrated/verified incorporated both internal and external constraints.

Internal constraints depend upon the physical characteristics of model components at the scale dimensions. A prime example of an internal constraint is the use of water as the fluid in the model, which limits the model's ability to reproduce viscous forces in the correct proportion. Internal constraints cannot be overcome without changing model scales, sediment material characteristics, fluid characteristics, and possibly operational procedures.

External constraints consist of prototype data availability, of funding limitations, of time restrictions, and on the relative degree of answer sought. The latter, relative degree of answer sought, plays a significant role in this process because some models were conducted simply to confirm a design already developed or to provide a visual demonstration of the expected results to other non-technical personnel. External constraints often serve as rigid constraints -- typically, external constraints cannot be avoided or modified without great difficulty.

Statements regarding capabilities and limitations for qualitative models should be tempered by a consideration of both internal and external constraints. Circumstances may exist where a qualitative model result is desired to confirm a technical opinion. In this case, the internal constraints of the model are understood. One acknowledges that the model may not fully depict prototype conditions, but the result aids in confirming (in conjunction with previous experience of similar problems, measured prototype data, or other model studies) that the proposed work will function as desired.

Absolute limitations, therefore, may only exist for individual applications. Ultimately, the person(s) responsible for developing a problem solution makes the decision whether to use a particular engineering tool or not. The present evaluation attempts to identify the principle internal limitations that exist and to describe the possible ramifications of those limitations. With this knowledge, a potential modeler can: 1) assess whether the micromodel provides the level of detail needed to assess the problem at hand, 2) determine whether alternate methods are necessary in lieu of the micromodel, or 3) determine if model efforts (numerical and/or physical) in addition to the micromodel are warranted.

In a general sense, the present evaluation identifies a need to suggest procedural changes in the application of models (numerical and physical) other than the micromodels as described herein. To the JV team's knowledge, no other model has been subjected to the level of scrutiny currently focused on the micromodels. Other models should be subjected to a similar review in order to determine their areas of applicability and if procedural changes are necessary.

5.3. ETTEMA AND MUSTE (2002) CONCLUSIONS (IS THIS THE SECOND TIME FOR THESE CONCLUSIONS?)

No 1st time for IIHR Flume info

Investigators at IIHR reported conclusions derived from the study of fixed bed flume experiments (Ettema and Muste, 2002). Those conclusions are repeated below for the reader's convenience.

1. Thalweg alignment and separation region in the vicinity of a dike in a loose-bed channel are functions of the parameters

$$\frac{u_{*o}}{u_{*c}}, \frac{Re}{\sqrt{f}}, \frac{We}{\sqrt{f}}, \frac{V_o^2}{gLf}, \frac{W}{Y}, \frac{L}{W}, \frac{R}{D} \qquad \text{(Set 3)}$$

Reynolds number, relative roughness, and resistance coefficient (Re, f, and R/D) characterize the approach flow distribution in which the dike is to be placed. Shear velocity ratio (u_{*o}/u_{*c}) characterized the state of bed-sediment mobility in the approach flow. These parameters, together with flow velocity head, aspect ration, and relative dike length (V_{02}/gLf, W/Y, and L/W) describe the flow field around the dike. The Weber number parameter $We/\sqrt{f}$ expresses the influence of surface tension, and is important for only very shallow flows.

2. When approximate constancy of the parameter $u*o/u*c$ is the primary similitude criterion used to operate a model for a dike of given W/L, distortion of the other flow parameters in Set 3 may influence thalweg alignment and separation region. The distortions, essentially stem from natural limitations in scaling sediment size, may cause scale effects that increase in influence as length scales (prototype/model) increase.

3. The scale effects became evident as the following deviations (values in model compared to scaled prototype values) in thalweg alignment and separation regions:

(i). As X_r [the horizontal scale ratio] increases, flow thalweg requires a longer distance, relative to dike length, to return to the channel centerline downstream of a dike. The distance downstream of the dike was almost three times as long for the channel equivalent to a micromodel than for the baseline channel [2.7 feet wide]. Figure 32 of the IIHR report indicates the distortion variation with X_r.

(ii). As X_r increases, the maximum lateral location of the thalweg, T_c, decreases until an asymptotic value of approximately (W-L)/2.

(iii). As X_r increases, the downstream flow-separation region contracted from $B_1/L \approx 14$ to $B_1/L \approx 4$ for the channel equivalent of a micromodel.

(iv). As X_r increases, the width of the flow-separation region decreased asymptotically to the length of the dike (i.e., $B_2/L \rightarrow 1$).

4.The flow parameters in Set 3 directly affect the distribution of pressure and local flow structure around the upstream face of a dike. Through that action, they affect the strength of wake eddies developed by a model dike. In consequence, the dike's wake region contracts in extent. The shedding of the strengthened wake eddies intensifies turbulence generated by the model dike. Increased turbulence generation and increased dispersion of turbulence results in a longer flow length, relative to dike length, for flow symmetry to re-establish downstream of a dike. Commensurately, it takes longer for flow thalweg to return to channel centerline.

5. The depth of local scour relative to dike length, d_{Se}/L, for a non-porous dike, increased as X_r increased from the baseline loose-bed channel to the channel comparable to a typical micromodel channel. The value of d_{Se}/L associated with the nominal micro-scale channel was about 3.5 times that for the baseline loose-bed channel.

6. Relative to channel width, the lateral extent of local scour increased as length scales reduced. For the non-porous dike in the baseline loose-bed channel, the local scour extended across two-thirds of the channel width. For the non-porous dike in the nominal micromodel channel, the extent of local scour extended almost the entire width of the channel.

7. Local scour reduces the length of the downstream separation region to $B_1/L=4$, for the baseline loose-bed channel and the channel comparable to a micromodel. A scour hole re-contours the channel bed so as to direct flow more directly behind a model dike. Increasing dike porosity, e, decreased depth of local scour, d_{Se} (Figure 44 of the IIHR report). The same proportionate reductions in d_{Se} occurred for the baseline loose-bed channel and for the channel typical of a micromodel channel. At porosity $e \approx 0.75$ to 0.80, $d_{Se} \approx 0$.

8. Increasing dike porosity, e, decreases the length of the thalweg excursion around a model dike (Figure 43 of the IIHR report). For the channel comparable to a micromodel channel, dike porosity between 0.50 to 0.80 produces a thalweg excursion similar to that for the baseline fixed bed channel. However, a dike with this porosity has no separation region.

5.4. CONCLUSIONS BY THE JV EVALUATION TEAM

Generally, assessment of each area considered in the evaluation begins with a consideration of the four levels presented earlier in Section 3.2.4. These are:

1. Demonstration, education, and communication
2. River Engineering - Qualitative
3. River Engineering - Quantitative
4. Navigability/Hydraulic Structures/ Flow Details

<u>I do not agree with these levels. See my previous comments.</u>

References to these levels are made by a numerical reference to the preceding list as appropriate.

5.4.1. Capabilities

1. **Micromodels can be used effectively to demonstrate and communicate complex hydraulic and sedimentation issues**. Demonstration of hydraulic and sedimentation principles in gross terms requires no specific model design. Simply having a flume

with flowing water and sediment serves to illustrate many basic principles. The addition of a model insert that represents a particular prototype reach only enhances the demonstration effect. The visual nature of the micromodel allows scientists that are not familiar with hydraulic or sedimentation phenomena to "see" how water and sediments interact within the channel.

2. **Micromodels provide an opportunity to educate various audiences (level 1).** This follows directly from the demonstration and communication aspects of micromodel capabilities. Often, local sponsors and other non-technical individuals have a vested interest in river processes. Use of the micromodel to help these individuals understand the complexities of river hydraulics provides a mechanism to arrive at desired project outcomes.

3. **Micromodels provide a means to qualitatively compare relative changes between alternative modification plans.** Past experience with micromodels indicates that after a period of calibration (where the model is adjusted to reproduce observed prototype conditions), various alternatives can be analyzed in a qualitative sense to aid in selection of a recommended plan of modification. The screening of alternatives in this way helps engineers and other scientists assess which alternatives provide the desired channel response. The relative comparisons are not used (and cannot be used) to indicate absolute elevations or dimensions in the prototype. Specification of absolute elevations and/or dimensions requires quantitative analysis beyond the scope of present micromodel methodologies. Qualitative comparisons are consistent with levels 1) and 2).

4. **Micromodels identify general scour and depositional trends.** The qualitative application of micromodels identifies overall behavior of the channel bed in response to various alternatives. The qualitative nature of general scour and depositional trends is consistent with level 2). Not the same

5. **Micromodels display the ~~same~~ general morphologic capabilities as the large models at WES. Comparative physical analysis conducted for both Micro Models and WES models show similar morphologic responses. (This should be elaborated on, we spent hundreds of man-hours on this effort and a discussion needs to be in the body of the report, or at least here in the conclusions).**

~~5.~~6. **Micromodels provide supplemental information for other model results (e.g. numerical or larger physical models).**

~~6.~~7. **Three-dimensional scour and deposition trends in rivers and streams.**

~~7.~~8. **Changes in thalweg location from imposed training structures.**

~~8.~~9. **Qualitative velocity trends and patterns: Examination of main flow concentrations and general flow direction. Flow pattern determination in response to bathymetric changes imposed to the streambed.**

~~9.~~10. **General navigation studies to bathymetric and flow pattern response.**

~~10.~~11. **Main channel and side channel bathymetric analysis and study. Rearrangement of the bed forms to decrease dredging and to improve or diversify aquatic conditions.**

~~11.~~12. **Qualitative analysis of the three degrees of translation freedom as described by Ettema in "A Framework for Evaluating Micro-Models."**

~~12.~~13. **Flow and sediment response trend studies at multiple entrances (tributaries) and outlets (distributaries).** (Mouth of the White River, Memphis Harbor, Morgan City)

~~13.~~14. **Analysis and resolution of outdraft at lock approaches and bridge crossings.** (LD24, LD25, Mouth of the White River, Morgan City, Vicksburg Front)

~~14.~~15. **Implementation of Bendway Weirs; flow and bathymetric response.** (LD24, SEMO Port, Mouth of the White River, Morgan City, Vicksburg Front)

~~15.~~16. **Innovative design of environmental river engineering structures, i.e. notched dikes, chevrons, hard points, etc.** (Copeland Bend, Bolters Bar, JB Bridge, Cottonwood)

~~16.~~17. **Channel contraction measures to reduce dredging.** (White River, Clarendon and Augusta; Savanna Bay, Copeland Bend, Bolters Bar, JB Bridge, New Madrid, Morgan City)

~~17.~~18. **Dike and closure structure modification to increase scour or flow within side channels and off channel areas.** (Sante Fe Chute, Marquette Chute, Schenimann Chute, Savanna Bay, Wolf Island, Salt Lake Chute, JB Bridge)

~~18.~~19. **Sedimentation patterns within slack water harbors.** (SEMO Port, Memphis Harbor)

~~19.~~20. **Stream realignment at bridge crossings.** (Big Creek)

~~20.~~21. **Analysis and study of inflow sedimentation of lakes.** (Slagle Creek)

~~21.~~22. **Deposition patterns at water intakes.** (Highbanks)

5.4.2. Limitations

1. **Unknown discharges used in the micromodel** - Prior to starting the JV evaluation, flows were largely unknown in the micromodel. A few exceptions where timed

volumetric measurements were made are the cases where model discharge was known. Model discharge was established by a visual assessment of the state of sediment mobility. Flows were largely unkown….how so???? The shape of the actual hydrograph was also unknown because control of model discharge was accomplished by specifying a valve opening. Huh? Meters were put in ??? what is the point trying to be made here? Implementation of flow meters in routine micromodel operation (beginning in 1999) alleviated these limitations. I'm confused.

2. **Operational sensitivity to position of by-pass line** - Prior to the JV evaluation, a by-pass in the delivery piping provided for adjustment of water delivered from the pump to the micromodel headbay. (What does this have to do with anything??) This was a setup of the past….There was a period where we didn't have any bypass and operated either by hand or variation of the pump…so what is the purpose???? Micromodels typically used flexible piping to convey water and sediment and any movement of the piping changed the distribution of flow between the by-pass line and the primary line leading to the model headbay. Changes in this distribution produced fluctuations in the amount of water delivered to the model. The primary concern with the by-pass occurred when sediment lodged in the pump intake requiring removal of the pump. After the pump intake was opened, replacing all of the flexible piping in the original positions was extremely difficult. Therefore, discharges delivered to the model were altered slightly. Because slight adjustments in any model operational parameter potentially causes significant changes in model bed response, a stable discharge was crucial to achieving model calibration. Implementation of a constant-head assembly in the micromodel procedures alleviated this limitation. (so why is this a limitation? Even if it was..what does it have to do with things today? Was this a result of the evaluation?

3. **Micromodels do not reproduce prototype stages**. (And they never will produce prototype stages…they are distorted models Stages directly impact the amount of energy in the model. Stages that are too low (Stages are not too low…stages are set to provide adequate energy in the model, you are not communicating to the reader the operation purpose of the model, this was described at length in a previous section…it also was described in the operational procedures of the WES models…this is not a limitation…a limitation is you trying to make the model into something it is not physically capable of reproducing or achieving…it is not a water surface model, never was, never will be..you cannot call a Ford a Chevy ….(using a stage of +20 LWRP in model to represent a stage of +30 in prototype) produce different velocity and sediment distributions within the channel cross-section. As a result, the ability of the thalweg to adjust laterally is restricted. the ability of the thalweg to adjust laterally is not restricted….as submitted…a model with a distortion of only 1.5 had problems reproducing the location of the thalweg…you do not have enough data to support this statement…and we could show we have data to conter this conclusionObservations in both micromodels and loose-bed flume studies support this. (there are observation in models with much less distortion that do not support this….)Additional problems arising from incorrect stage pertain to overtopping of training structures. Where stages are too low, structure elevations must be

adjusted vertically to achieve the "appropriate" level of overtopping flow. Such adjustments are necessary to obtain a desired lateral velocity distribution in the model channel. These adjustments lead to the possibility for misinterpreting model data when converting to prototype scales.

Simulation of incorrect stages (what are correct stages? Don't understand this? Someone is failing to understand how distorted models work…this is very confusing to me and I am sure the reader!)in the micromodels coupled with vertical scale distortion leads to a velocity distribution associated with a narrow-deep channel (model) as opposed to a wide relatively shallow channel (prototype). Therefore, model shear and velocity distributions do not represent prototype conditions. The narrow and deep channel that exists in the micromodels precludes full development of 2-dimensional and 3-dimensional velocity distributions.(totally speculative and not supportive) Micromodels have an overly restricted thalweg -- the model thalweg cannot adjust laterally within the cross-section with the same degree of flexibility that occurs in the prototype I don't agree. Where is the proof?. Narrower channels and increased vertical distortion produces a larger deviation in velocity and shear distributions from prototype conditions. Inadequate representation of stages limits micromodels to levels 1) and 2). (*What is inadequate??)See earlier comments!

4. **Micromodels do not represent prototype discharges**. Current operation of micromodels using a cyclic hydrograph ~~touts the claim~~ that "model hydrographs mimic the average annual response of the prototype." This statement is inflammatory. However, adoption of flow meters into routine model operation revealed that the cyclic hydrograph provides only a limited representation of a true hydrograph cycle. The problem with the cycle lies in the control valve hardware -- the valve provides insufficient resolution and control to obtain the desired hydrograph cycle. Present discharge hydrographs in the model vary on rising and falling limbs due to the valve operating characteristics. Lack of control near minimum and maximum flow settings result in operation of the model at minimum/maximum flows for a disproportionate period of time. Improvements in the valve hardware are essential to provide consistent and predictable control of model discharges. Such improvements provide the capability to develop design hydrographs that more closely mimic prototype discharge trends. But would this improve the model? We don't know this for sure.

Current discharge control limits micromodels to levels 1) and 2) because the variable discharge drives development of desired bathymetry. The model hydrograph should provide a representation of prototype discharge characteristics. ~~Achievement of more consistent control of discharge does not translate to the use of micromodels in levels 3) and 4).~~ As discussed earlier, the models are never used at these levels so why discuss it. The models are not able to forecast the weather but we don't discuss it. Other factors play a more significant role in expanding the use of micromodels to these levels.

5. **Micromodels have exaggerated Froude numbers**. Exaggeration of Froude number in loose-bed models results from efforts to obtain similar sediment mobility between the model and the prototype. The exaggeration in Froude number results from velocities that are higher than required for Froude similitude. The higher velocities are required to produce the dynamic similitude prescribed by u_*/u_{*c}. Accordingly, flow parameters

influenced by mean stream velocity (V or V^2) are likewise exaggerated. Ettema argues additional points on the effect of exaggerated velocity head ($V^2/2g$).

A simplified consideration of the energy equation demonstrates the effect of exaggerated velocity head.

$$\frac{P_1}{\gamma} + Z_1 + \frac{V_1^2}{2g} = \frac{P_2}{\gamma} + Z_2 + \frac{V_2^2}{2g} + \text{Losses}$$

where, P is pressure, Z is elevation, V is mean stream velocity, g is the unit weight of water, g is the gravitational constant, the subscript 1 denotes an upstream location, the subscript 2 denotes a downstream condition, Losses represent all energy losses between location 1 and 2. Losses include frictional/roughness losses, form losses, and contraction losses among others. Losses are generally a function of V^2. Therefore, exaggeration of velocity significantly impacts the energy relationship. Contraction losses represent the effects of dikes and related training structures~~. Exaggerated velocities have a negative impact on flow patterns and flow/velocity distributions, particularly in the vicinity of training structures (Ettema's report and observations from micromodels and UMR flume work~~ I didn't see this). ~~A similar negative impact occurs in channels with pronounced curvature (e.g., sharp bends).~~

Froude number (and velocity) exaggeration limits micromodel usefulness to levels 1) and 2). It should be clearly stated that the models have never been meant to to used in levels 3 and 4. Use of micromodels should be restricted to these levels based upon current micromodel approaches. Where required to provide a demonstration tool for levels 3) and 4), micromodels may be used with extreme caution, but only in conjunction with other model results and adequate explanation by experienced personnel. Future developments in the micromodel may enhance model capabilities by reducing velocity and Froude number exaggeration. Recent use of a lighter weight sediment material, Polyester PlastiGrit Type I, tends to reduce the slope required to achieve sediment mobility which in turn reduces the Froude number exaggeration.

6. **Surface velocity patterns are adversely affected by scale distortions and exaggeration of Froude Number.** We have data from a large model with extremely low distortion that did not reproduced the correct velocity distribution because the correct bed was not reproduced, channel thalweg location, etc. This cannot be ignored…Increased distortion of the vertical scale results in model channels having smaller B/y than found in the prototype channel. Circulation in channels with small B/y ratios is stronger as evidenced by observations in the laboratory and in small streams. Davinroy (1994) presents corroborating isovelocity data for prototype and model at a cross-section in the Dogtooth Bend reach of the Mississippi River (Figures 5-1 and 5-2, respectively). (you have got to be kidding me? What are you trying to do here Andy? Do you think that this one cross section is going to support your conclusions?? How accurate do you think the anometer was? You are contradicting the use of flow visualization….Visualization was used to show general trends in this case, it was not used to make exact measurement comparisons….we have stressed this point many times and you have agreed how it

should be used,..yet now you are using visualization out of the blue to quantify? To try and support a case???? Why? Don't understand this.....~~D~~avinroy's figures depicting isovelocity contours indicate a somewhat stronger circulation pattern in the ~~m~~micromodel than found in the prototype. Although there are similarities between the prototype and the model in that both exhibit several higher velocity cells across the channel width, the lateral distribution is different in the micromodel than shown in the prototype (Figures 5-1 and 5-2). The prototype data show the highest thread of velocity located approximately 250 feet from the left bank position while the micromodel data show the highest thread of velocity at a distance of 400 feet, a difference of 150 feet. The difference of 150 feet between these locations may appear minor. However, this represents approximately 10 percent of the total channel width (unbelievable that you are using the visualization in this manner....you are contradicting your own reservations about the use of flow visualizations and are trying to use it way beyond what it is meant to be..

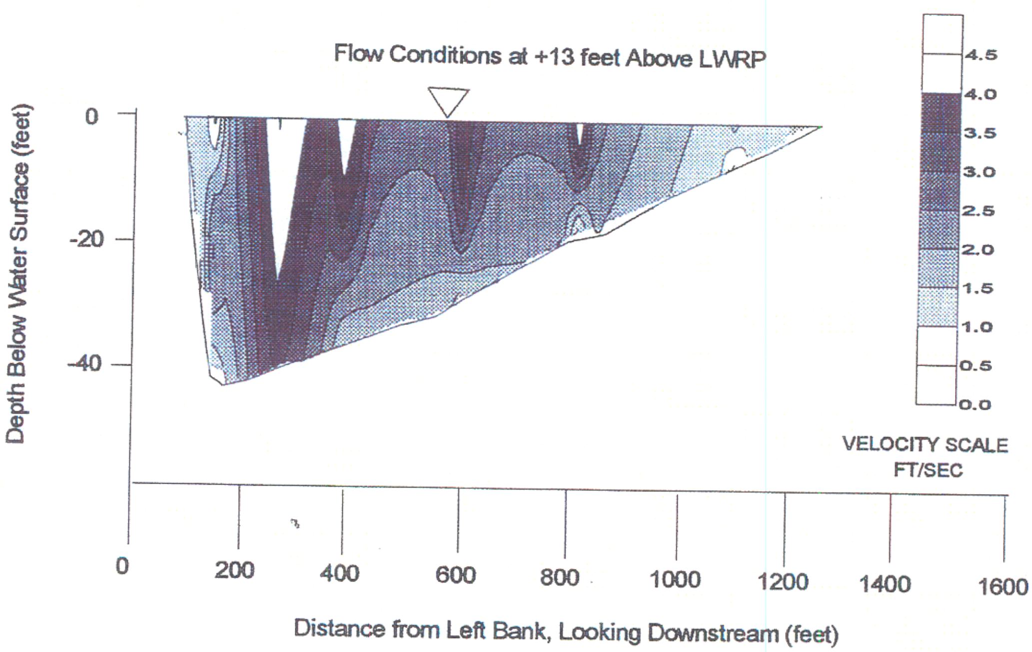

Figure 33. Cross Sectional Velocity Isovels at Mile 34.3, Prototype

Figure 5-1 Cross Section Isovelocities at Mile 34.3, Dogtooth Bend Prototype, Mississippi River (Davinroy, 1994)

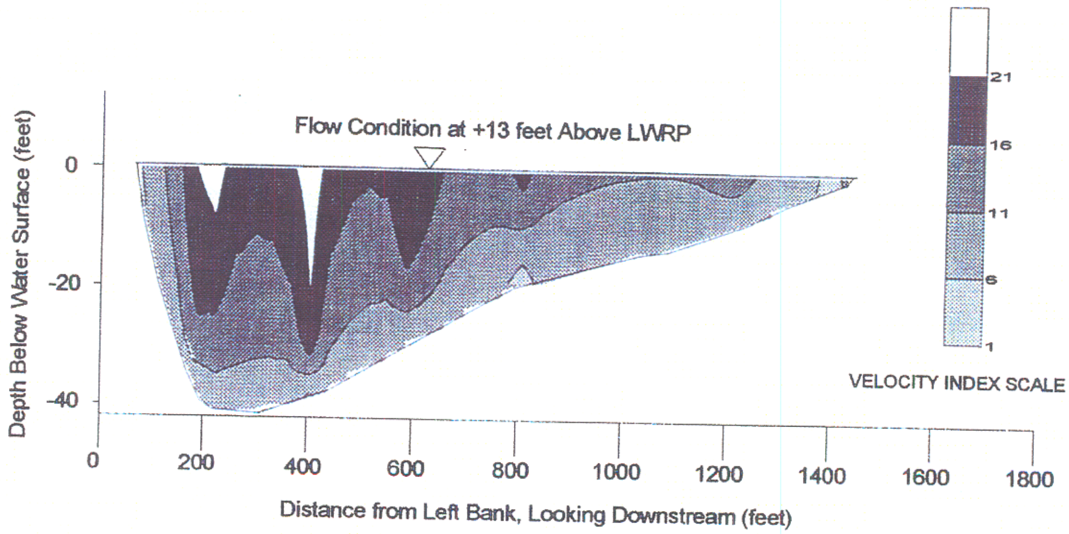

Figure 34. Cross Sectional Velocity Index Isovels at Mile 34.3, Micro Model

Figure 5-2 Cross Section Isovelocities at Mile 34.3, Dog Tooth Bend Micromodel (Davinroy, 1994)

7. **Roughness characteristics in the micromodel are not adequately scaled.** The lack of appropriate roughness in micromodels is closely associated with their inability to reproduce prototype stages. Estimates of friction factors and roughness coefficients for micromodel sediments and flow conditions indicate that roughness is too low in micromodel channels. In other words, the model boundary is too smooth. What in the model is too smooth?

~~Because stages (and depths) are not correctly reproduced in micromodels, surface flow patterns are not correct. Surface flow patterns have greater errors for prototype reaches containing a high degree of flexibility in thalweg position (not laterally constrained) and/or having high sinuosity.~~ I do not agree.

Based on flume tests by Gaines (2002) using flow depths typical in micromodels, micromodel sediment has an average Darcy f of 0.11 that is equal to a Chezy C of 27 $m^{1/2}$/sec. This value is consistent with values for model C presented in Gujar (1981) who found C = 25-30 $m^{1/2}$/sec for fine and coarse sand, 20-25 $m^{1/2}$/sec for fine bakelite, and 25-35 $m^{1/2}$/sec for coarse bakelite. The micromodel value can be compared to typical Mississippi River values of C = 50 $m^{1/2}$/sec. With a distorted Froude model, achieving the correct friction requires the ratio of C in prototype to model be equal to the square root of the distortion. With a typical distortion of 11 and a prototype C = 50 $m^{1/2}$/sec, model C would have to be 15 $m^{1/2}$/sec. While we know the micromodel is not a Froude model, these values show that the micromodel, having a typical C of about 27 $m^{1/2}$/sec, is too smooth which is generally the case with distorted models. The model smoothness issue is a possible explanation of why high stages are difficult to run in the micromodel and maximum stage is limited to about +20 LWRP in Mississippi River channels where bankfull is about +30 to +35 LWRP. At higher stages, velocity becomes too great in the model. Similarity of friction is also important in simulating flow in bends. Although the micromodel has an extreme exaggeration of relative roughness, the model is too smooth because of the large vertical scale distortion. (which model, and which distortion?? again…you are generalizing….some models with higher distortions behaved better than models with lower distortions)…Use the models as a test and not just your flume tests.

9. Model Shields Parameter Less than Prototype - Graf's category of empirical or qualitative loose-bed models has model Shields parameter less than the prototype. Qualitative loose-bed models also use lightweight sediments, vertical scale distortion, and slope increase but only to achieve an acceptable level of sediment transport. Glazik and Schinke (1986) describe loose-bed models experience using a model Shields parameter significantly less than the prototype. As quoted in Glazik and Schinke (1986), results from Liebs (1942) and the assumption of a specific gravity of 2.65 results in a Shields parameter of 0.030 that represents "initial movement of single grains", 0.047 represents "initial, though slow, transformation of the bed", and 0.076 represents "beginning of vivid bed material movement". Model design and operation in Glazik and Schinke (1986) is based on a model Shields parameter of about 0.061. The prototype in their report, for which a model study case history was presented, had a prototype Shields parameter of 0.51 which shows that using 0.061 in the model is a significant relaxation. The Mississippi River and other major alluvial rivers often have Shields parameter in excess of 1.0. Hecker and White (1989) describe a loose-bed models used on the Arkansas River where the Shields Parameter was less than the prototype. Based on personnel communication with Tom Pokrefke and Charles Nickles who conducted ERDC coal bed loose-bed models, "beginning of vivid bed material movement," or a Shields parameter of 0.076, best described the techniques used at ERDC. Although actual depths and slopes used on the coal bed models suggest a Shields parameter that is closer to 0.061, either 0.061 or 0.076 show a significant reduction of Shields parameter was used in the ERDC models. Chitale ((19??) states that movable bed model design is based on "adequate tractive force to ensure satisfactory bed movement". Shen (1990) states that if the rate of sediment movement is not an issue and the only need is to create a movable bed, a Shields parameter need only be greater than the critical value. The use of loose-bed models for bed similarity studies without having equality of Shields parameter is consistent with conclusions by Laursen and Alawi (1989) regarding the effects of velocity on scour. Laursen and Alawi (1989) found that scour was independent of shear/critical shear ratios greater than about three to four.

The few slope measurements taken in the micromodel have shown a slope of about 0.01. At a maximum stage in the micromodel of +20 LWRP, the hydraulic depth is about 35 ft in typical Mississippi River applications. The hydraulic radius is about 83% of the hydraulic depth for a distortion of 11 which is an average distortion value used in micromodels. Using a typical vertical scale of 1:800 results in a model hydraulic radius of 0.036 ft. Using a specific gravity of 1.47 and a model D_{50} of 1.0 mm, results in a typical Shields parameter used in the micromodel of 0.23. This value is compared to prototype values on the Mississippi River that are typically greater than 1.0.

The micromodel Shields parameter is closer to the prototype than in both the model by Glazik and Schenke (1986) and the coal bed models at ERDC. Because of the importance given to the Shields parameter in the rational approaches of Yalin and Einstein and Chien, some might be tempted to conclude this is a favorable feature of the micromodel. However, it happens in the micromodel because of the large vertical scale distortion in conjunction with the large Froude number distortion. The experience of previous qualitative models by Glazik and Schenke (1986) and the ERDC coal bed models is toward a significantly lesser Shields parameter resulting in general bed movement. This approach allows the modeler to minimize vertical scale distortion and Froude number exaggeration.

The primary advantage of smaller Shields parameter in the model than in the prototype, and almost certainly the reason its use has evolved, is that distortions in Froude number and vertical scale can be reduced, which should result in improved reproduction of the flow field and thus improved reproduction of the bed morphology. Another factor concerning the Shields parameter is its effect on the time scale for sediment movement. Small models having large Shields parameters will respond extremely fast. Such rapid response reduces testing time but was intentionally avoided in * the ERDC coal bed models. * What is lacking in this report is the fact that you have a variety of models we looked at with both large models and micro models that contained varying distortions…If higher distortion is bad, then you have contradicting data supplied by the models….. you cannot ignore these models….(again, we will use a case study with a model with low distortion as an example)

* Which operated very near the critical tractive stress

10. Slope distortion in the micromodels is too high. Slopes in the micromodels are highly tilted to achieve a desired state of sediment mobility using the PlastiGrit Type II sediment material. (slopes are not highly tilted…relative to what….explain??i ~~Exaggeration of model slope tends to restrict thalweg adjustment laterally within the channel.~~ This results from exaggerated velocities and from a prototype channel represented as a narrow and deep cross-section. The latter results primarily from the vertical scale distortion. ~~Distortion of slope produces velocities that are not necessarily reproduced correctly in terms of magnitude and direction.~~ (disagree…data shows optherwise…you will have to break this out because it does not represent our view….. ~~Incorrect reproduction of velocity magnitude and direction leads to incorrect reproduction of flow details.~~ Current slope distortions used in micromodels limit applications to levels 1) and 2). (see previous paragraph)

11. Micromodels operate on a sediment equilibrium principle. Use of the equilibrium concept for micromodel operation becomes a limitation only if prototype bathymetry results from a non-equilibrium condition. Where the prototype undergoes constant changes in boundary conditions (bankline migration, rapid scour or deposition trends, etc.), the equilibrium approach may lead to incorrect model results. The potential for incorrect model predictions increases as the rate and magnitude of the non-equilibrium condition in the prototype increases. Micromodel use is restricted to problems where prototype banks do not change appreciably over time and where the prototype exhibits no long-term aggradation-degradation trends.

12. Sediment materials used in micromodels limit their application to sand- or gravel-bed streams with active bed transport. The PlastiGrit sediment material behaves in a similar manner to sand. Simulation of bed response with a cohesive bed is beyond the capability of existing physical and numerical models. Tthe mechanics of cohesive material erosion and transport is not understood and no empirical methods exist to simulate channel adjustment.

~~**13. Tributary and divided channels impose requirements to ensure adequate representation of flow and sediment distributions between the respective channels.**~~

14. **Adequate documentation of micromodel operational and design parameters facilitates a better understanding of how the model represented the prototype.**

15. **Availability of prototype data limits understanding of some boundary conditions.**

16. **Suspended sediments cannot be modeled using micromodel techniques.** Sediment material characteristics change appreciably when sizes are in the clay and silt range. Suspended sediments at prototype scale typically fall in the silt/clay particle sizes with some suspended sediments being as large as sand sizes. However, cohesionless materials in the prototype having a median particle size of even 1.0 mm would require model sediments in the clay sizes if the correct horizontal and vertical model scales are used. At such reduced, sizes otherwise cohesionless materials exhibit cohesive characteristics. Therefore, model sediment sizes are distorted in order to maintain cohensionless bed transport. The sediment sizes thus used in models do not provide any mechanism for simulating suspended sediments in the prototype. What physical model simulates suspended sediment? This is evident from the Shields Regime diagram (Figure 3-5). This paragraph should be under item #12 above.

17. **Inability to achieve good verification in some previous micro model tests (Not sure where this is going, but if you read the Dogtooth Bend section, or the St. Louis Harbor section…one can argue on what constitutes good verification….**

18. **Conclusions from consultant on applicability to only laterally constrained reaches (How many times do we want to talk about the conclusions from the consultant??)** We are not required to agree with Ettema's conclusions.

19. **Differences in Kate Aubrey plan tests** and base test (As opposed to what?????)

20. **Lack of repeatibilty of Kate Aubrey traditional micromodel tests** **What is this about???**

21. ~~Poor replication of currents in Vicksburg Front model~~ **(totally disagree…poor replication in float survey and misinterpetation of field data, which does not adequately describe flow in the main channel)**

22. ~~Unknown % flow splits in divided channel reaches~~ **(Unknow flow splits existed in many WES models, including Dogtooth Bend (2 side channels) Tower Rock, and others…Flow splits are not necessary to calibrate the bed….already discussed at length in face to face meetings**

23. **Unknown flow characteristics through notches/dikes**..**thus the purpose of a model…**

24. **Water Surface Profile Analysis (in channel and floodplain)**?????

25. **Floodplain Sedimentation**?????

26. ~~Velocity Magnitudes~~ model was never meant to look at this

27. ~~Quantitative & Near Field Scour and Deposition Analysis~~ model was never meant to look at this

6. RECOMMENDATIONS

6.1. PROTOCOL FOR MICROMODELS

With insight regarding current applications of the micromodel methodology and potential limitations of the micromodel, the potential modeler must decide on the appropriate course of action: 1) The micromodel provides the necessary outputs for analyzing the problem at hand or 2) Other means must be sought to analyze the problem. If the decision to conduct a micromodel study is made, the necessary procedures are then outlined in order to achieve the desired outcomes.

The following sections describe procedures for calibration of the micromodel that will serve to develop confidence in the model results.

6.1.1. General

In order to achieve confidence in loose-bed model results, certain steps are required. First, model design should follow accepted techniques and use a consistent methodology. Second, analysis of model results should include a quantitative estimate of model and prototype agreement for the calibration condition if time permits. Third, documentation of model design and operation parameters and their relationship to the corresponding prototype parameter values is necessary.

Proper interpretation of model results requires that model operation adhere to certain basic procedures. That is not to say that all models involve exactly the same steps to achieve calibration or to perform alternative comparisons. Indeed, there are different constraints placed on each model situation. These constraints depend upon the problem to be solved (e.g. degree of technical complexity and/or human expectations/perceptions), on the availability of prototype data, and on the availability of time/funding. A detailed description of the problem[6] begins the modeling process.

[6] The description should include sufficient details to provide a general statement defining why prototype conditions are undesirable and to provide specific data (e.g. flow paths, velocities, bathymetry, dredging history, navigation reports, etc.) that define the problem as quantitatively as possible.

6.1.2. Problem Definition. The problem must be defined and study objectives stated. This includes specific qualitative descriptions of the problem or problems so the modeler can determine the applicable model limits and establish a general approach for conducting the model effort. The specific problem location is identified and described regarding one or all of the following:

1. Extent of problem
2. Inadequate Navigation Depth
3. Inadequate/Undesirable Channel Alignment (navigation, bridges, etc.)
4. Undesirable flow distribution through main channels and side channels
5. Environmental adaptations of existing structures
6. Environmental enhancement objectives
7. Undesirable Depositional Patterns
8. Bank stability/Recession
9. Excessive Dredging Requirements
10. Evaluating changes in/Effects of existing structures
11. Entrance and Exit conditions that may be relevant to the problem?????

The problem definition also helps in developing model study objectives, which should be stated prior to beginning model design. Objectives often include: defining the location of training structures, establishing general controlling elevations for the structures, and a projection of prototype channel response to proposed changes. Where existing structures are analyzed to determine their effects, goals include establishing whether modifications are required to produce a desired outcome (e.g. where dikes are notched to provide back channel areas for environmental purposes).

6.1.3. Procedures

Model methodology should include the following steps as part of the calibration process.

1. Verify and describe the way that the model reproduces the problem(s) as observed in the prototype.

2. Verify and describe how the model reproduces the thalweg alignment found in the prototype. Some expression of goodness-of-fit should be provided. This can be accomplished by plotting the morphologic parameter of thalweg location by Range for model and prototype data. Calculation of the MSE and

differences are also ~~required~~ to describe the level of overall agreement for the model.

3. Check other morphologic parameter values to insure that model values are not too far from prototype values. This step is important because the hydraulic geometry of the channel affects the model's representation of velocity and sediment distributions. Area and depth are principle parameters to be considered and emphasis should be given to keeping model areas and depths within a certain tolerance of prototype values. Present data do not support a rigid criteria to be applied. Future research may help establish a required level of agreement. The required level of agreement should be based upon the effects that result from deviating from an ideal representation of prototype channel characteristics. Until additional research defines a required level of agreement, recommended tolerances are to keep model parameter values within one standard deviation of the prototype reach-averaged parameter values. Where this is not feasible, limited regions may be permitted to deviate by no more than two standard deviations of the prototype reach-average value. As a general guide, model values should not deviate from prototype values by more than approximately 1/3 of the respective prototype values at any location within the model reach.

4. Document the use of techniques to limit scale effects in the model. The use of artificial bank roughness (wire mesh along the banks), the placement of clay along the bank to provide sloped banks or to adjust roughness, and the use of "non-erosive" materials in the model to limit scour depths are techniques currently used in the micromodels. A map of locations digitized from the model where these features are used provides the recommended method for documenting the use of these techniques.

6.1.3.1 Calibration Process.

The intended use of the model also affects the calibration measures to be employed. Where prototype geometry is relatively simple and only general trends in bed response are sought, calibration requires only a one-step process. ~~Where prototype geometry is complex a two-step calibration process becomes necessary to establish the degree of confidence that can be placed on the model results. Where surface flow paths are to be used in high-risk problem solutions, a third step becomes necessary.~~ I don't necessarily agree. This has not been proven to be a more accurate method of calibration.

6.1.3.2 Basic Calibration.

A single-step calibration process involves achieving agreement between model and prototype bathymetry. The level of agreement between model and prototype bed elevations serves to establish the degree of confidence that the modeler places on model results. Morphologic similarity can be established by determining model and prototype values for thalweg position, cross-section area, top width, hydraulic depth, and the width divided by the depth.

6.1.3.3 Complex Prototype Conditions.

A two-step calibration process includes the preceding step but adds a second verification process. The second step involves taking conditions after the base calibration timeframe where changes have been observed in the prototype and then placing those changes in the model. The model response to those changes is compared to the observed prototype changes in order to confirm (or verify) that the model adequately reproduces model conditions. The second step provides an additional level of confidence necessary when dealing with complex flow situations. Typical complex flow situations include a channel with one or more sharp bends, a channel division, a channel confluence, or where hydraulic structures are present (i.e. bridges, locks and dams, or similar structures). The verification step also uses morphologic similarity to assess model and prototype agreement. This step will most likely be impossible to accomplish in most circumstances. In an ideal world you do this. However, there is not much chance of having data before and after a single clear cut change was implemented.

Split flow conditions within the model reach require an additional measure to assure the proper distribution of flow between the separate channels. LSPIV techniques provide a semi-quantitative measure of the model flow distribution. Prototype division-of-flow data provide a means to determine or at least bracket prototype flow distribution.

6.1.3.4 Surface Flow Patterns.

The large fixed bed models used a zero step process. The three-step calibration process becomes necessary when surface flow patterns are used to assess model response. Here, the model response includes the relative comparison of various alternatives. Confirmation of surface flow patterns in the model with prototype data provides the third calibration step. The high degree of vertical scale distortion and the large exaggeration in Froude number influence surface flow patterns in the micromodels. This influence results in model flow patterns that may be different than prototype flow conditions[7]. For this reason, use of the surface flow patterns obtained from a micromodel requires extreme caution. Confirming the general location and alignment of surface flow patterns in the micromodel with observed prototype flow pattern data provides a means to overcome the unknown influence of vertical scale and Froude number distortion on model surface flow patterns.

The significance of the third step increases when the problem under consideration involves a hazard or risk to human safety. Hydraulic theory and observations by investigators who? indicates that surface velocity distributions can have deviations of ten percent or more of the channel with in channels with a high degree of scale distortion. Because a deviation of ten percent of the channel width may have a major impact on interpretation of model results, the use of a micromodel as the sole basis for assessing alternatives in a high-risk situation is problematic and should be avoided. Other methods such as features designed external to the micromodel[8] This footnote is confusing. Please explain in the main text., two-dimensional numerical models and/or larger-scale loose-bed physical models ~~should~~ could be used in conjunction with micromodel flow visualization results to assess recommended alternatives. Sometimes, there are no models used for assessing alternatives in a high risk situation. Therefore, if I have got only enough time and money for a micro model, then that is what should be used. However, if time and money are available, then the other methods will increase your confidence and reduce the risk. What is the risk when you don't have time or money for any model study? There are many other ways to effect the amount of risk in a design. What is the risk of using ADCP data to analyze any model result?

Although not mandatory, it is strongly suggested that surface flow patterns be recorded using both time exposure photography and video footage. While the time exposure photography captures a single image of the seeding particles, a video recording

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[7] The word may is used at this point to signify that the influence is largely unknown by looking only at model data.

[8] The hydraulic design of artificial scour protection in the vicinity of a bridge is one example of such a feature.

of the seeding can provide a more complete understanding of the flow patterns. The video recording also provides an excellent demonstration tool for explaining the similarities and differences between the model and prototype flow patterns and between various alternatives and the base test. I do agree that the flow visualization should be compared to actual prototype data. What is the best way to do this?

6.1.4. Similarity

The observed degree of similarity for a particular model study ~~should~~ could be documented through the Shields regime diagram, the roughness distortion graphs, the morphologic similarity graphs, and the Froude similarity criterion. Documentation of similarity relationships provides information necessary for correct interpretation of model results.

Model design should incorporate an assessment of the Shields criterion for both prototype and anticipated model conditions. The degree of Froude number exaggeration should also be calculated. The roughness and slope distortion should also be evaluated. The Shields criterion and the roughness and slope distortion factors provide a mechanism for balancing sediment mobility and boundary roughness effects in the model. Applying the ripple factor, which is a function of the sediment transport, is a useful way to achieve this balance. The current research indicates that increased sediment material particle size (e.g., increased D_{50}) will improve roughness similarity in the micromodel.

6.1.5. Improvements Resulting from Evaluation

Early during the course of conducting the evaluation, severe deficiencies in the micromodel procedure were modified. The two main modifications included the adoption of flow metering and the use of a constant-head system for delivering water and sediment to the model. This was not the result of the evaluation effort. We identified these needs well before hand and were working on solutions.

Standard micromodel methodology should incorporate the use of flow meters to document model discharges and hydrograph shape.

Standard micromodel methodology should incorporate the use of a constant-head assembly to deliver water and sediment to the model headbay.

6.2. DATA REQUIREMENTS

Previous model study data were insufficient to assess even basic similarity criteria. Data were also insufficient to evaluate scale effects. Because similarity criteria and scale effects are important to understanding and interpreting model results, future model studies should document sufficient information to allow assessment of similarity criteria and scale effects. Data needs are relatively straightforward and should require minimal increases in model time and cost. The benefits derived from collection of these data are two fold: 1) understanding scale effects may permit wider application of the models to solve problems of a more quantitative nature and 2) understanding the distortion of slope, velocity, Froude number, hydraulic radius and sediment transport may produce better overall model similarity than presently exists. The minimum data necessary to achieve these benefits include the following:

1. (*) Model reference plane (e.g. flume) transverse and longitudinal slopes.

2. (*) Model water surface elevations (in model coordinates) in at least three locations continuously throughout the hydrograph cycle so that model water surface slopes can be documented. If continuous readings are not feasible, model water surface elevations should be obtained at maximum and minim discharges as a minimum. Locations of measurements should also be documented in model coordinates (x,y,z coordinates in inches or mm depending on the method used for surveying the model).

3. (*) Model discharge throughout the hydrograph cycle. As a minimum, the maximum and minimum discharges used for the calibration case should be documented in numeric form. The shape and duration of the hydrograph should be reported (graphic form preferrable).

4. (*) Prototype discharge in at least two locations and at two water surface elevations (one near the minimum stage to be modeled and one near the maximum stage to be modeled). Water surface elevations (e.g. water surface slopes) are also required to document the conditions for when discharge measurements were made.

5. (***)Volumetric sediment transport in the model after calibration (obtained by timed capture of a volume of water and sediment or other means).

6. (*) Gradation of model sediment material. Model sediment gradation can be determined for batches of sediment material or for individual models with minimal cost and time.

7. (*) Gradation of prototype sediment material. Approximate prototype sediment gradations are available for the lower Mississippi River and can be easily obtained for other channels.

8. (*) Model bathymetry in model coordinates (pre-conversion to prototype coordinates). Why?

9. (**) Model morphologic parameter values in model coordinates (pre-conversion to prototype coordinates). Locations of ranges to be used in generating morphologic parameter values can be identified by digitizing left and right bank points on the model with the Microscribe™ or Faro Arm™ and then obtaining the corresponding prototype locations by conversion of the model range coordinates into prototype coordinates with the convert utility.????

10. (*) Model morphologic parameter values (at prototype scale) for comparison of calibrated bathymetry to prototype values (see 11).

11. (*) Prototype morphologic parameter values for each prototype bathymetric survey utilized in the study effort.

(*) Denotes required data None of this should be required due to time and cost constraints
(**) Denotes highly desirable data
(***) Denotes desirable data

Sediment transport measurements in the prototype are also needed to assess similarity in sediment transport. However, the costs associated with measurement of sediment transport (particularly bed load) and the inherent inaccuracies of measuring sediment transport in large alluvial rivers preclude acquisition of this data on a routine basis. Sediment transport in the prototype may be estimated using standard transport relationships (e.g. Yang, 1978). Measurement of prototype sediment transport is desirable to verify/develop coefficients used in the various transport relationships. Prototype sediment transport data should be acquired as budgetary constraints permit.

Use of a standard form or forms to document the information provides a systematic way to acquire and publish the known data listed above. A draft format is under development and will be provided with the final version of the report.

6.3. ADDITIONAL RESEARCH

Loose-bed models described in this report can provide a reliable means for design and analysis of river training structures subject to the limitations described previously. Through application of loose-bed models, the modeler can gain insight into various prototype responses to structure designs. Projected prototype response can also be investigated to determine impacts on channel behavior. Further research on applications of small-scale loose-bed models can enhance methods for applying these models. However, additional data needs to be collected in present and future model studies to facilitate this research.

~~The present investigation proposed four categories of similarity depending on the level of detail required, on the risk to human life, on the relative solution accuracy and on operational constraints. A FMEA can help identify important criteria needed to define each category. Future investigations should focus on defining the categories used in the FMEA.~~

A primary goal of the present evaluation included estimation of scale and scale distortion effects in the small-scale models. This goal was not achieved. Data available from the previous model study results were insufficient to assess scale effects. A minimal amount of data collected from on-going and future model studies can provide the requisite inputs for defining scale studies and relaxation of scale ratios. The necessary data are included in the recommended micromodel protocol.

Variability in prototype bathymetric data has a major influence on the attainment of model similarity. Additional investigation of this variability may yield methods for weighting individual Range data (temporally and spatially) in order to define required similarity criteria.

Simulation of prototype discharges should mimic prototype hydrograph tendencies. Where prototype hydrographs are variable, model hydrographs should be developed so that model discharges behave in a similar fashion. The effect of variable hydrographs on bed development are only partly realized in current loose-bed modeling. The effects of simplified sine wave or triangular type hydrographs versus alternate hydrograph shapes (including rapid rise, rapid fall, and constant discharge) warrants additional study. We don't know if mimicking prototype hydrograph tendencies will have a positive effect on bed development. This should be considered for future study.

Limited testing performed on structure porosity as a relaxation technique should be expanded to determine how structure porosity impacts model bathymetry. Structure porosity plays a significant role in reducing the local scour tendencies and deflection of the surface flow patterns and thalweg location in small-scale channels. Optimization of the porosity effect is desirable and warrants further investigation.

Present applications of the loose-bed models provide only a qualitative representation of training structures. Quantitative application of loose-bed models to achieve optimized training structure designs requires the reproduction of details in the model. These details pertain to flow and sediment transport phenomena and to structure lengths and heights. Model sensitivity to changes in structure length and to structure height must be investigated before advancements can be achieved in structure design optimization. Is there any model or river engineering technique that can optimize a dike design?

Current investigations included a limited number of experiments involving a short contraction structure. Additional experimentation is necessary to define the impacts of channel width on flow and depositional characteristics in the vicinity of short contractions. Further research is also needed to determine the effects of channel width on flow and bathymetric response in the vicinity of long contractions.

Bed material gradation has a major impact on model roughness characteristics. Both roughness coefficients (e.g. Chezy C or Darcy-Weisbach *f*) and the relative roughness are affected by the D_{50} particle size. Because roughness also impacts selection of vertical scale (through the roughness distortion factor), the distortion of bed material size requires greater relaxation of slope and roughness similarity for the model. The ripple factor (μ_f) provides an indication of the degree of similarity relaxation required for a given slope distortion, roughness ratio, and sediment particle size. The present research developed a technique for approximating the value of μ_f. However, actual values of μ_f are necessary for model and prototype to permit adjustment of roughness (through the vertical scale and sediment particle size) to compensate for the relative influence of suspended sediment transport. Approximating the value of μ_f requires collection of data in prototype and model systems. Additional research should attempt to quantify this correction factor.

Reproduction of scaled water surface elevations in the small-scale model depends on the roughness characteristics of the sediment material and on the slope distortion used in the model. The degree of Froude similarity employed in model design also directly impacts the water surface elevations. Accurate model water surface elevation data are required to assess morphologic similarity in native model units. Currently, water surface elevation data are limited. A means for tracking water elevations in the model is required to determine model cross section areas, widths, and depths in the model.

The ability of the small-scale models to predict prototype response was investigated for the Kate-Aubrey reach of the Mississippi River. Additional confidence in the model technique can be gained by similar analysis of additional reaches where recommended model alternatives have been constructed in the prototype. Cases where model study results led to construction of the recommended alternative in the prototype should be sought where field data can be collected to compare with predicted model response.

The current evaluation considered the similarity of loose bed physical models. A similar evaluation of numerical sediment transport models was not found in the literature. Comparisons of numerical model results to prototype conditions using the morphologic parameter approach described herein should be accomplished. Comparisons should be performed for the calibrated model conditions and for a predicted model response.